National Aeronautics
and Space Administration

An Overview of Advanced Air Mobility (AAM) and NASA’s AAM Mission

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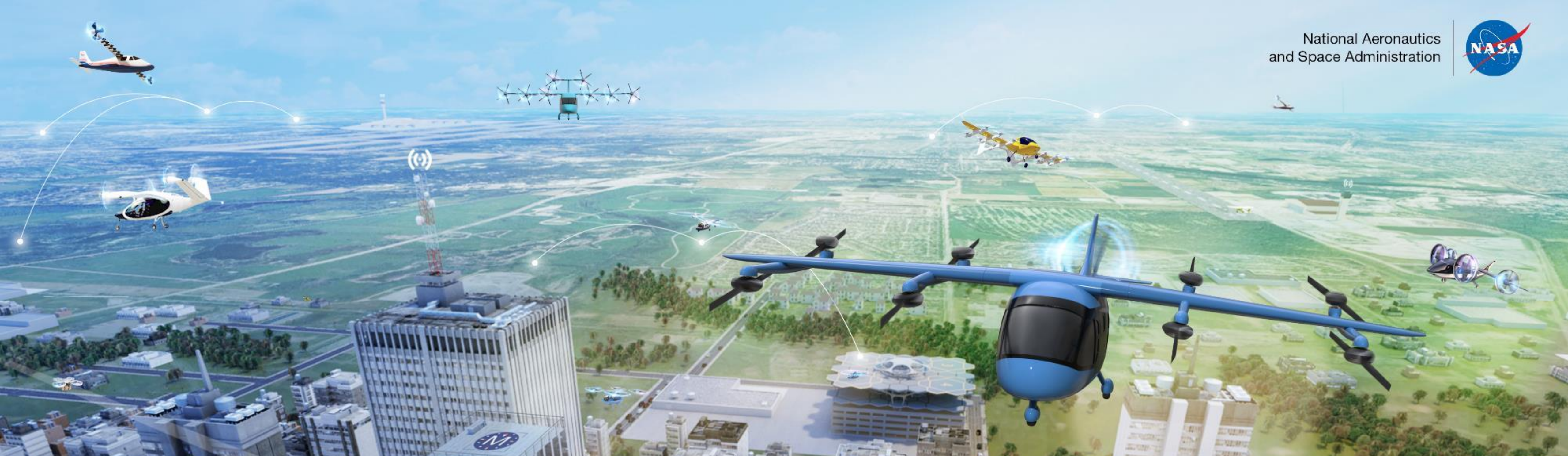

Presentation Outline:

I. Overview of AAM

II. Brief History of AAM

III. Overview of NASA's AAM Mission Work

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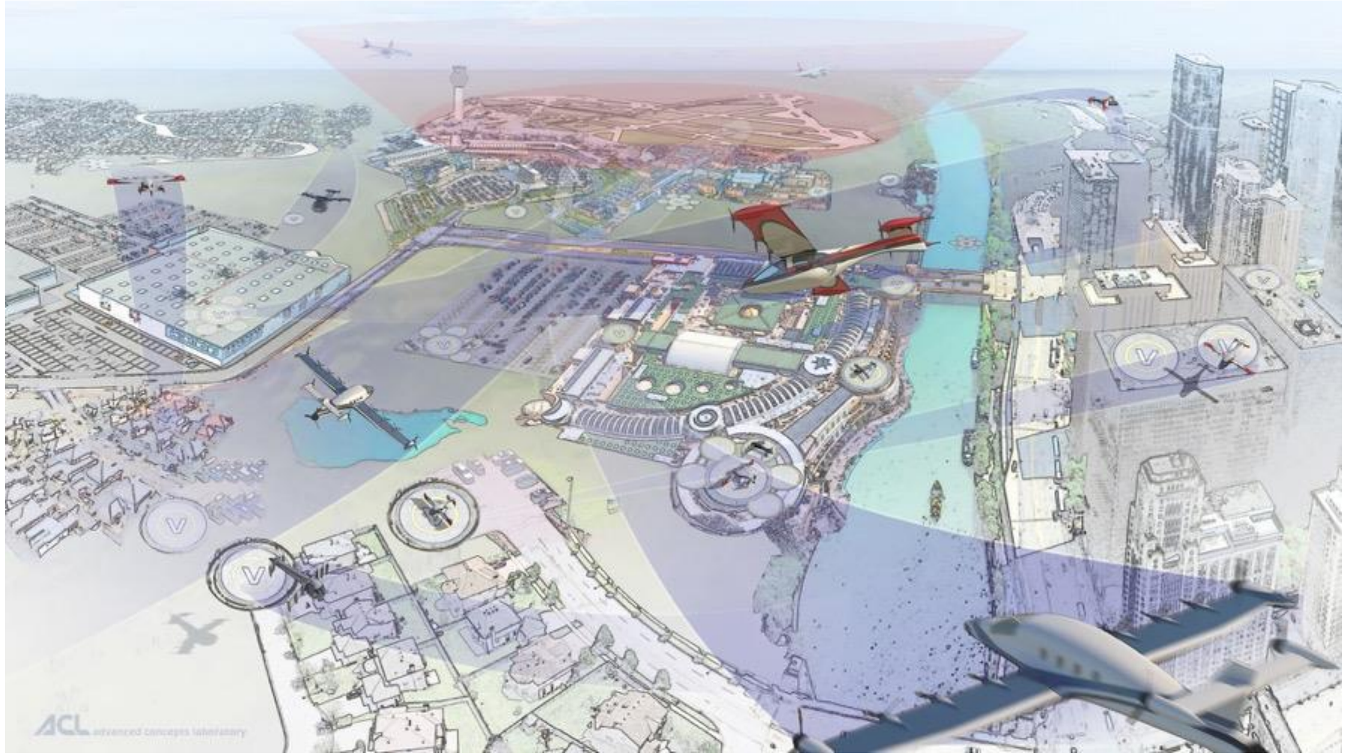
Overview of AAM

Advanced Air Mobility (AAM) Mission

Safe, sustainable, affordable, and accessible aviation for transformational local and intraregional missions

Advanced Air Mobility (AAM): Bringing Aviation into Daily Life

- Three primary application categories:
  - Urban Air Mobility (UAM)
    - “Local” missions up to ~75 miles around metropolitan areas
    - Largely novel “vertiport” infrastructure
    - eVTOL, potentially eSTOL or eCTOL aircraft
    - 1 to ~6 passengers or equivalent cargo
  - Small/Medium Unmanned Aircraft Systems
    - Local missions for aerial work or (small) cargo delivery (e.g., food, small packages)
    - Range of required takeoff/landing infrastructure from none to specialized
    - Typically VTOL-capable aircraft
  - Regional Air Mobility (RAM)
    - “Intraregional” missions up to ~500 miles
    - Primarily utilize existing (smaller) airports
    - eCTOL and eSTOL aircraft
    - Up to 19 passengers or equivalent cargo



- AAM is generally enabled by electrification & automation
- Many potential uses, including
  - Passenger transport
  - Cargo/package delivery
  - Emergency services/public good (e.g., air ambulance, EMT transport, etc.)
  - Aerial work (e.g., infrastructure inspection, photography, tourism, etc.)

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Brief History of AAM

AAM is a Convergence of the General Aviation and UAS Communities

AAM can be traced back to the early 2000s.
Interest has grown exponentially since the late 2010s.

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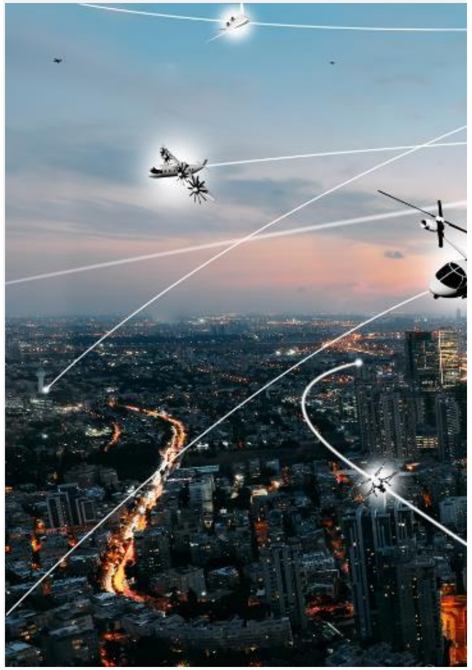
Overview of NASA's AAM Work

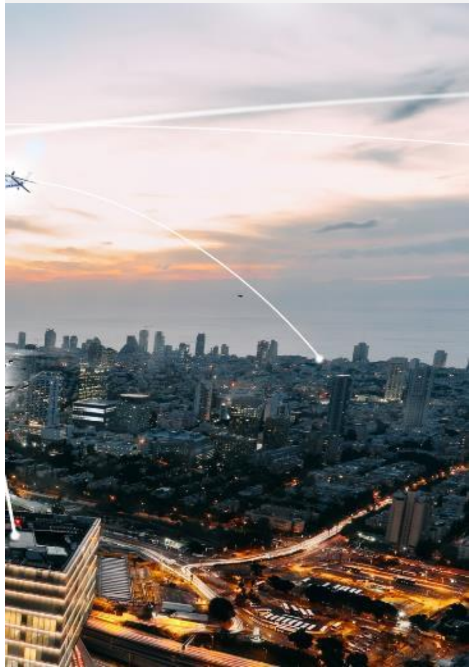
Addressing AAM Challenges

Vehicle Development and Operations



Airspace Design and Operations

Community Integration

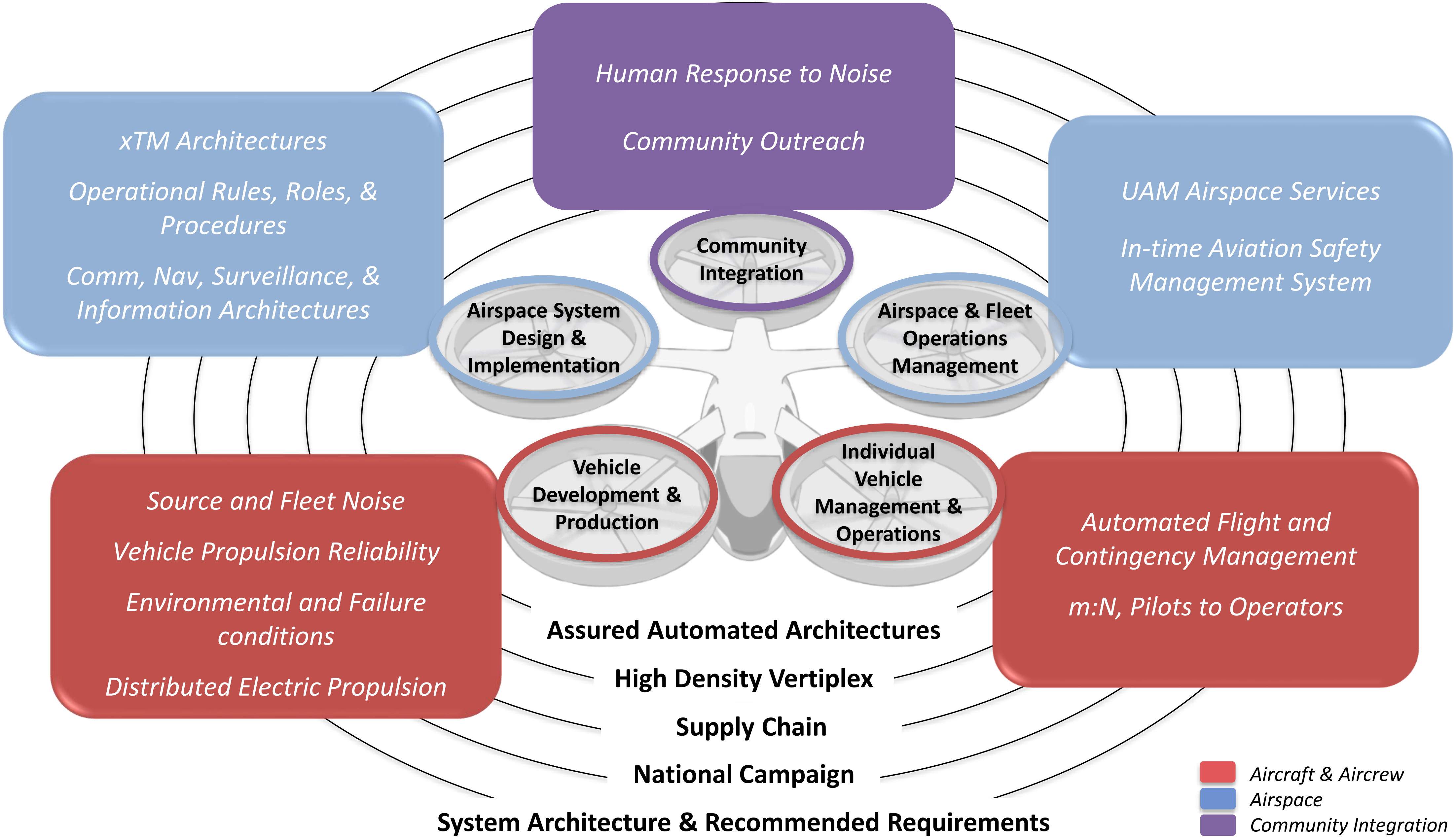


NASA and key partners are collectively taking on the most difficult mission challenges to enable industry to flourish by 2030

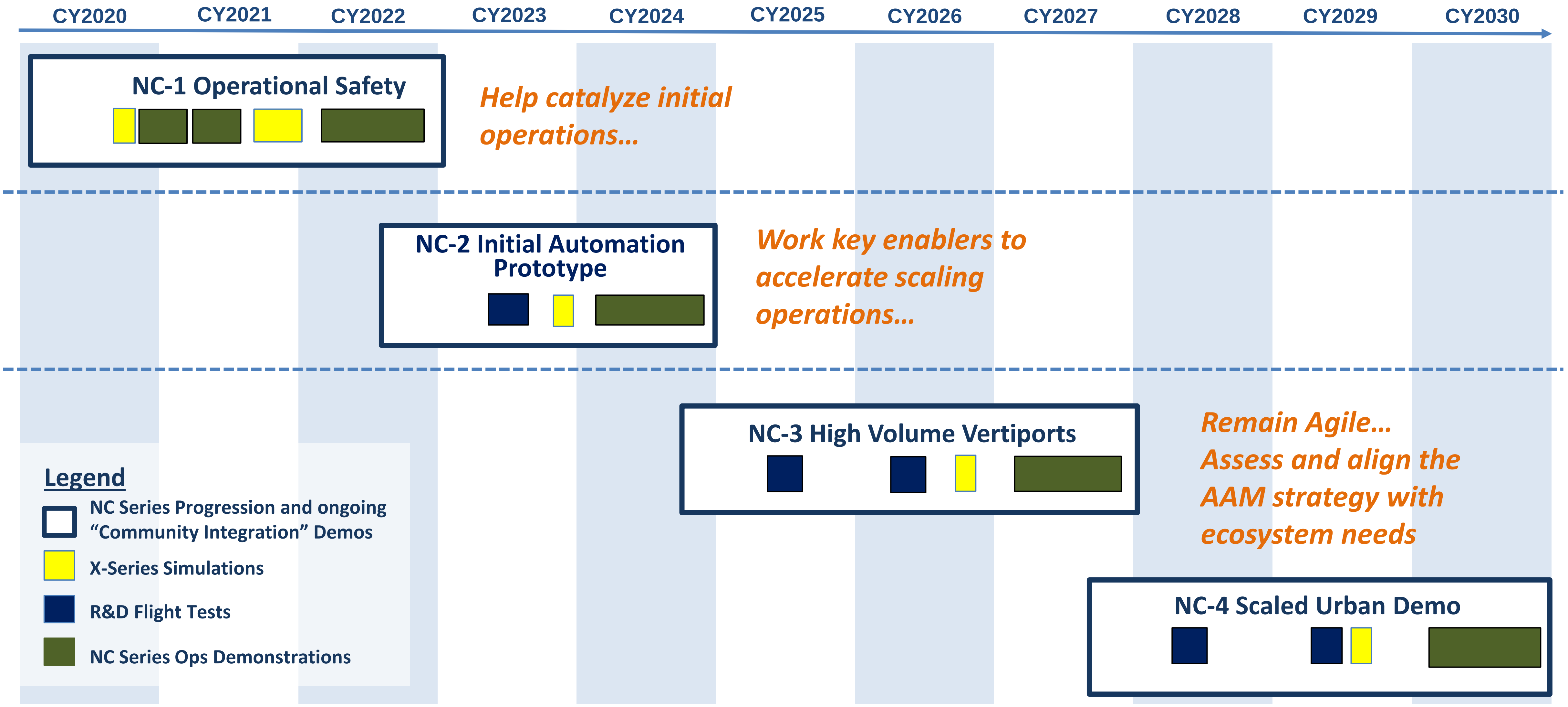
- **Research and Development Portfolio**
- **AAM National Campaign Series**
- **Robust Ecosystem Partnerships**

NASA to deliver long term technical solutions, system architectures, and recommended requirements for the industry and regulatory communities

NASA AAM Mission Priorities



National Campaign Series Overview



AAM Ecosystem Working Groups

Align on a common vision for AAM

Learn about NASA's research and planned transition paths

Adopt a strategy for engaging the public on AAM

Collectively identify and investigate key hurdles and associated needs

Develop AAM system and architecture requirements

Support regulatory and standards development

Form a connected stakeholder community

See https://nari.arc.nasa.gov/aam-portal/ for more information

Accelerate the development of safe and scalable AAM flight operations by bringing together the broad and diverse ecosystem

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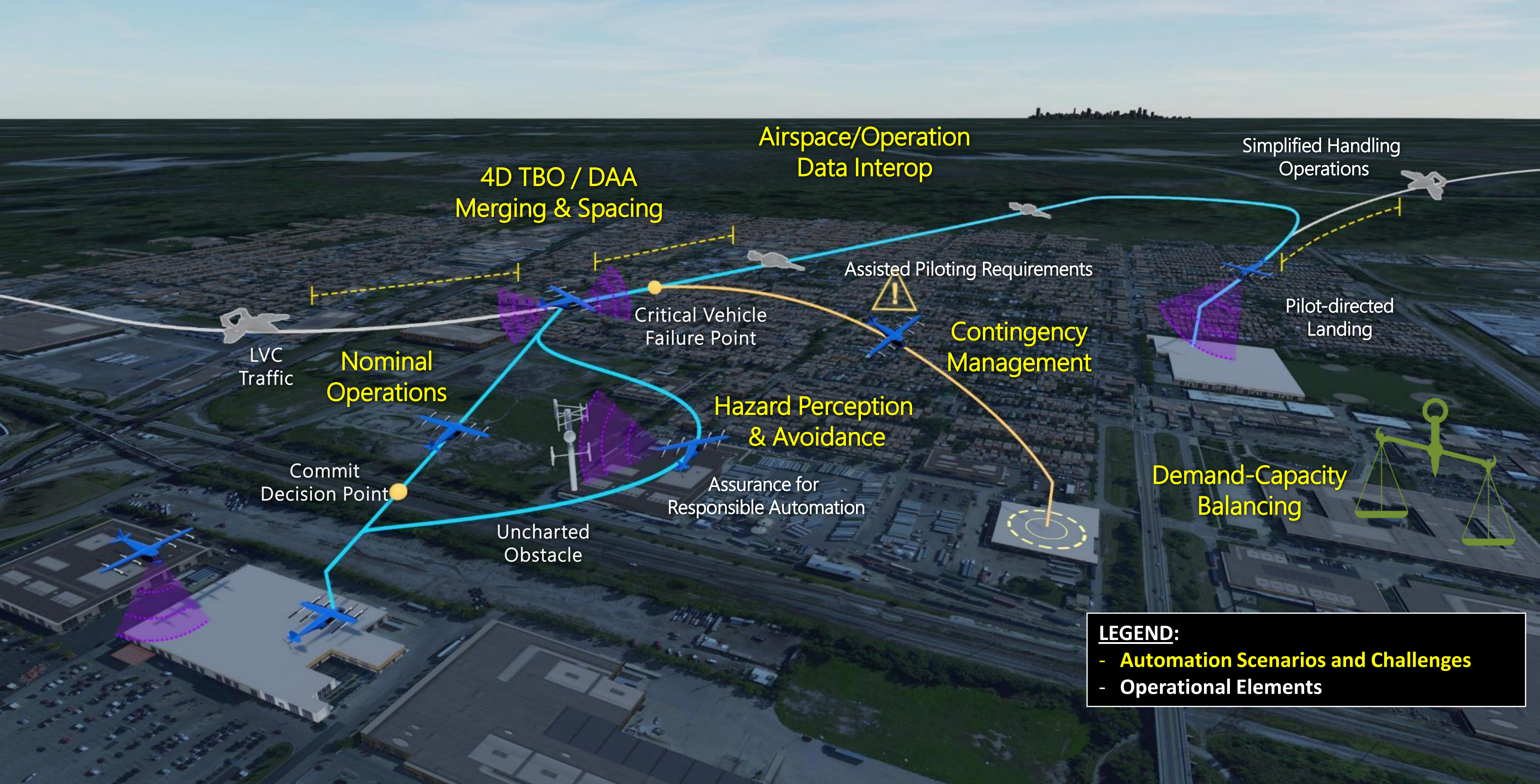
Discussion / Questions

NASA NC-2 Complex Operations OV-1



Automated Flight and Contingency Management (AFCM)

Automated Flight and Contingency Management

Develop and evaluate an initial, integrated suite of key vehicle automation functions to enable simplified piloting in urban environments and propose recommendations to enable certification and approvals for the selected concepts.

Community state of the art

- Approaches to enable UML-4 automation architectures include piloted, remotely piloted, and "automated"
- Working groups targeted at developing standards for simplified vehicle operations (SVO) and Assured Vehicle Automation architectures
  - FAA EZ-Fly, ASTM F44.50, and GAMA EPIC
  - ASTM SAE, and RTCA working groups established around automated aviation technologies

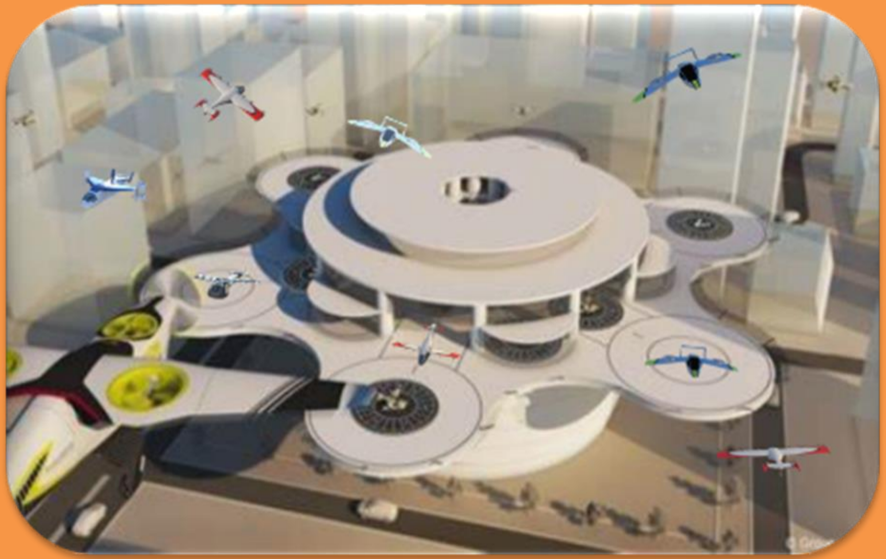
Community challenges

- Technology development, standards, and training to enable automated nominal and contingency operations
- VV&C procedures and standards for all automated vehicle and airspace architectures
- Security and public trust for automated aviation systems

NASA Role

- Leverage NASA expertise and facilities to develop and test complex vehicle automation architectures
- Collaboration partnerships with industry and OGAs to advance critical vehicle automation technologies

High Capacity UAM Ports



High Capacity UAM Ports

Develop requirements and architectures for integrated High Capacity UAM Ports in a Vertiplex environment; with an emphasis on vertiport automation, including its interactions with the UAM broader system, to accelerate safe and efficient vertiport operations as part of a scalable UML-4 system.

Community state of the art

- sUAS community progressing towards efficient Part 107 and Part 135 approvals, via technology enabled BVLOS operations.
- The maturity of automation in sUAS operations is low and limits the scalability and complexity of operations.
- Limited community understanding of procedures and interoperability of automated systems

Community challenges

- Receiving safety credit for integrated automation technologies that holistically address operational hazards and safety cases
- Vehicle-airspace-infrastructure interfaces that support effective data exchange for situation awareness and decision making
- Airspace technologies, services, and interoperability supporting high throughput operation in dense airspace

NASA Role

- Demonstrate prototypes focused on integrating NASA technology capabilities to advance automated sUAS operations
- Leverage sUAS to development concepts, architectures, procedures, and technologies to enable NC-3 High Volume Vertiports
- Leverage lessons from UTM integration for mission to advance sUAS across all NASA centers

UAM Airspace Architectures and Services

UAM Airspace Architectures and Services

Collaborate with Industry and the FAA to evolve the notional UAM architecture towards a secure prototype airspace UML-4 architecture to identify and validate airspace UML-4 requirements.

Community state of the art

- Technologies and procedures in the NAS today will support initial commercial UAM operations
- FAA enterprise systems are foundations for air traffic management
- FAA provides key services, such as separation assurance with ATC

Some Key Community challenges

- Initial commercial UAM operations cannot scale using current technologies and procedures in the NAS
- Researching and developing a federated approach to air traffic management, relying on 3rd-party services (i.e., services not provided by FAA)
- Identifying community-based rules

NASA Role

Lead industry to continue building framework for UAM airspace management through research and testing

- Prototype scalable systems
- Community based rules (CBRs) and recommended requirements to the FAA, standards bodies, and working groups
- Technology transfers to the FAA
- Industry-built UAM services as airspace provider for vehicle OEM in NC-1 flight test

Pathfinding for Airspace with Autonomous Vehicles (PAAV)

Pathfinding for Airspace with Autonomous Vehicles (PAAV)

Develop concepts, procedures, and technology to enable airspace access for air cargo operations with targeted autonomy in lower complexity airspace shared with conventional aircraft

Community state of the art

- Large UAS flights are possible with special accommodations
- Current air traffic management system is not able to support routine “file and fly” of increasingly autonomous aircraft integrated with current airspace operations

Community challenges

- Acceptance of large-scale usage of autonomous aircraft
- Airspace integration at a systems level
- Balance viability for Unmanned Aircraft operators and safety and efficiency for ATC and all airspace users

NASA Role

- **Development of algorithms and services** for flow, trajectory, and contingency management
- **Defining requirements** for integrating airspace management services with vehicle technology, and infrastructure
- **Documenting system performance requirements** informed by simulation and field activities

m:N Fleet Management

m:N Fleet Management

Enable scalable operations to achieve the full vision and potential of advanced air mobility through development of targeted tools and techniques critical for m:N operation of autonomous fleets

Community State of the Art

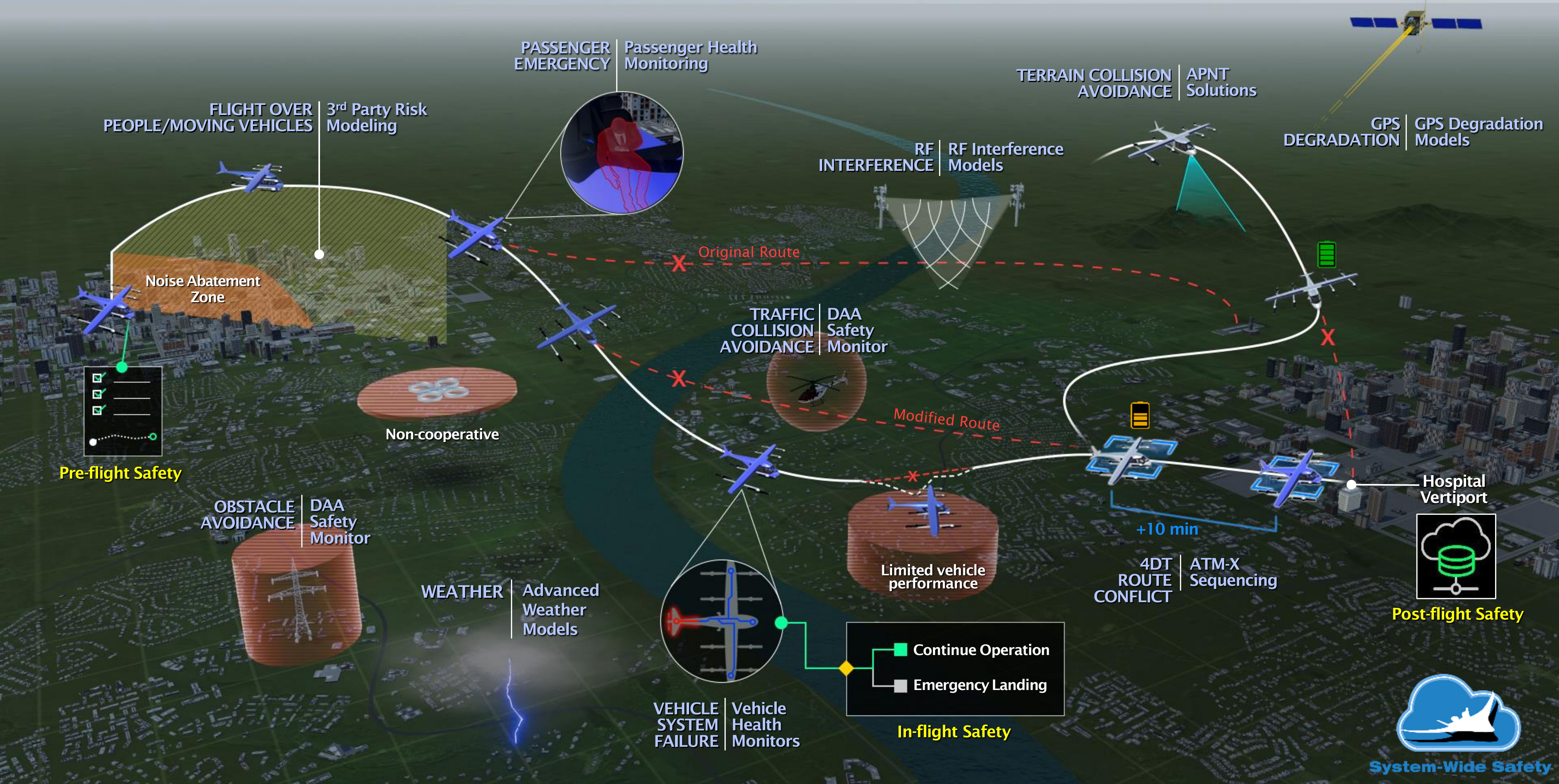
- m:N is a path to scalable, more profitable industry
- Robust m:N tech development underway in multiple industries, including package delivery and passenger operations
- US regulations limit m:N operations to outside the NAS (e.g., BNSF), under protected programs (e.g., FAA's IPP, PSP) or in other countries (e.g., Wing, Zipline)
- NASA's m:N WG is coordinating the community beginning with joint identification of barriers

Supporting NASA capabilities

Human-Autonomy Teaming:
Develop tools and techniques to enable a small number of humans (m) to manage many autonomous vehicles (N) across disparate scenarios and dynamic relationships; Coordinate m:N WG

Autonomous vehicle technology:
Develop a capability description of a UML 5 autonomous vehicle through characterization of realistic **Intelligent Contingency Management** and **Perception** functions

Developing a Safe Automated System for Scalability



What is an eVTOL aircraft?

- eVTOL = electric vertical takeoff and landing
  - Mix of all-electric, hybrid-electric, fuel cell power systems
- Many configurations – no clear "dominant configuration"
  - Multirotor, (multi) tiltwing, (multi) tiltrotor, fan-in-wing, separate lift + cruise, compound helicopter, tiltduct, blown flap/tiltduct, advanced rotorcraft, etc.
- Common characteristics:
  - 1 to 6 person payload
  - Shorter hover duration than typical rotorcraft
  - Often considerably shorter ranges than conventional aircraft

All images are NASA reference aircraft: https://sacd.larc.nasa.gov/uam

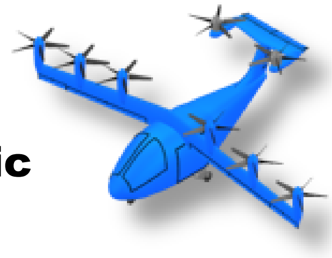
Research Areas for UAM eVTOL Vehicles

PROPULSION EFFICIENCY
light, efficient, high-speed electric motors
power electronics and thermal management
efficient powertrains
power quality standards
high power, lightweight battery
light, efficient small turboshaft engine

PERFORMANCE
aircraft optimization
rotor shape optimization
hub and support drag minimization
airframe drag minimization

ROTOR-ROTOR INTERACTIONS
performance, vibration, handling qualities
aircraft arrangement
vibration and load alleviation

Quadrotor + Electric



Tiltwing + TurboElectric

Side-by-side + Hybrid

Lift+Cruise + TurboElectric

SAFETY and AIRWORTHINESS
FMECA (failure mode, effects, and criticality analysis)
component reliability and life cycle
crashworthiness
Electric motor reliability assessment
propulsion system failures
high voltage operational safety
high voltage protection devices

NOISE AND ANNOYANCE
low tip speed
rotor shape optimization
flight operations for low noise
aircraft arrangement/ interactions
cumulative noise impacts from fleet ops
human response to noise
active noise control
cabin noise
electric motor noise
Recommended metrics and requirements

STRUCTURE AND AEROELASTICITY
structurally efficient wing and rotor support
rotor/airframe stability
crashworthiness
durability and damage tolerance
high-cycle fatigue

OPERATIONAL EFFECTIVENESS
disturbance rejection (control bandwidth, control design)
Ops in moderate to severe weather
passenger acceptance/ ride quality
cost (purchase, maintenance, DOC)

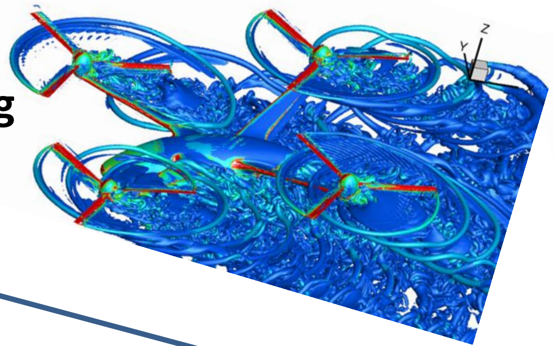
ROTOR-WING INTERACTIONS
conversion/transition
interactional aerodynamics
flow control

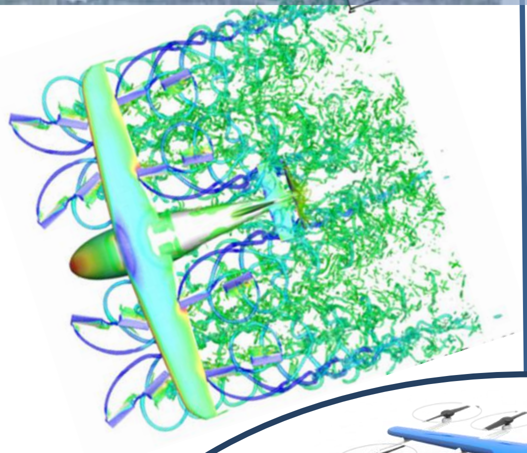
AIRCRAFT DESIGN
weight, vibration
handling qualities
active control

Red = primary RVLT research area
Blue = secondary RVLT research area

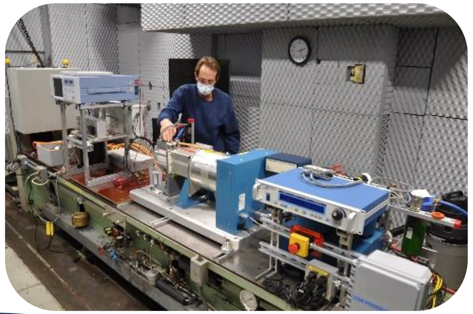
RVLT Concept Vehicles for UAM: Integrates Research Across Disciplines

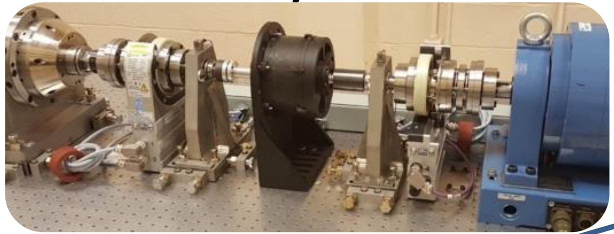
Vehicle Modeling Tools



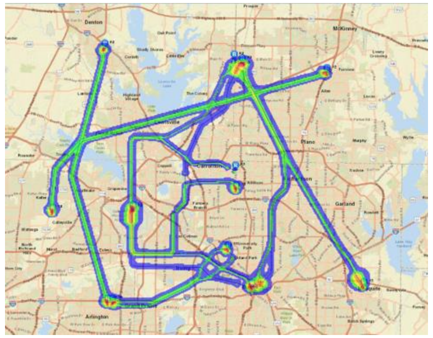


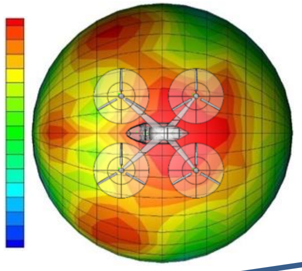
Electric Powertrain Reliability





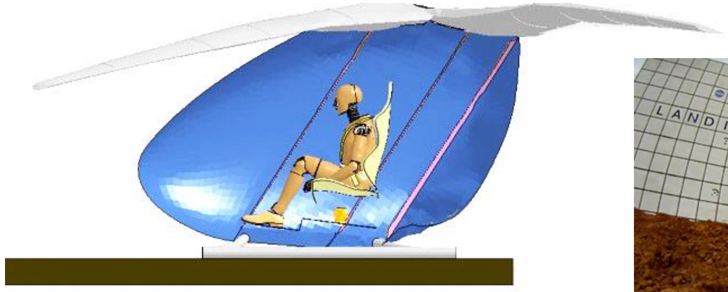
Fleet & Vehicle Noise





Handling & Ride Qualities

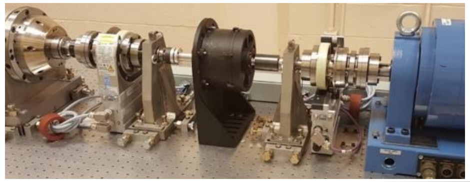
Crash Safety



Validation Testing

Revolutionary Vertical Lift Technology (RVLT) Near Term Focus for Research
FY21-FY23

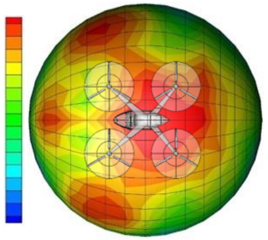
Vehicle Propulsion Reliability



Tech Challenge: Reliable and Efficient Propulsion Components for UAM

- Re-configure laboratories for electric propulsion testing
- Conduct initial single string tests
- Develop tools to assess motor reliability
- Develop high reliability conceptual motor design

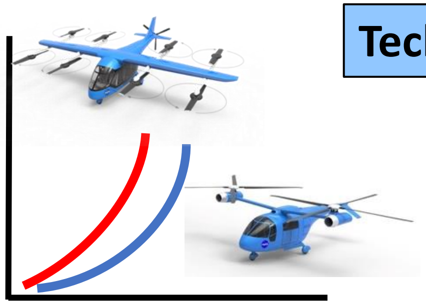
UAM Fleet Noise



Tech Challenge: UAM Operational Fleet Noise Assessment

- Generate Noise Power Distance (NPD) database for several Urban Air Mobility (UAM) reference configurations and trajectories
- Conduct fleet noise assessments
- Initiate psychoacoustic testing to assess human response to UAM vehicles

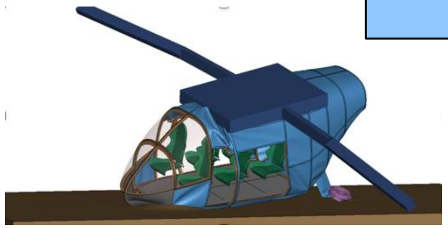
Noise and Performance



Tech Challenge: Tools to Explore the Noise and Performance of Multi-Rotor UAM Vehicles

- Plan and conduct validation experiments
- Improve efficiency and accuracy of conceptual design tools
- Conduct high-fidelity configuration CFD for validation and reference
- Improve community transition and training for analysis tools

Safety and Acceptability



Targeted Research in These Areas for Future Tech Challenges

- UAM crashworthiness and occupant protection
- Acceptable handling and ride qualities for UAM vehicles
- Ice accretion and shedding for UAM